Contents

Briefing Charts

Bioastronautics Initiative

BIOASTRONAUTICS

Bioastronautics

- Benefits health and well-being of people on Earth
- Integrates a total program leading to <u>safe</u> human space operations
- Capitalizes on NASA's infrastructure

The Bioastronautics Initiative will surmount medical and technological barriers to promote safe, productive, and autonomous human activity beyond low-Earth orbit.

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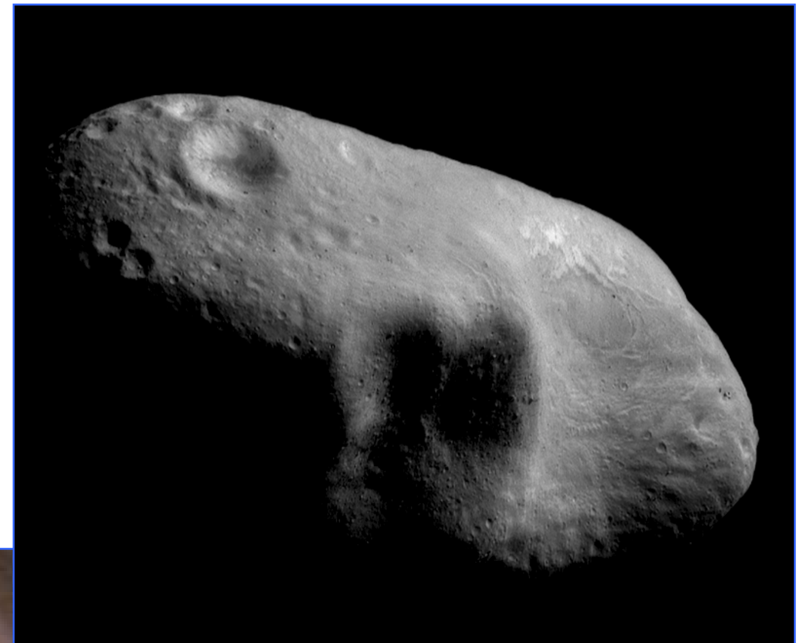
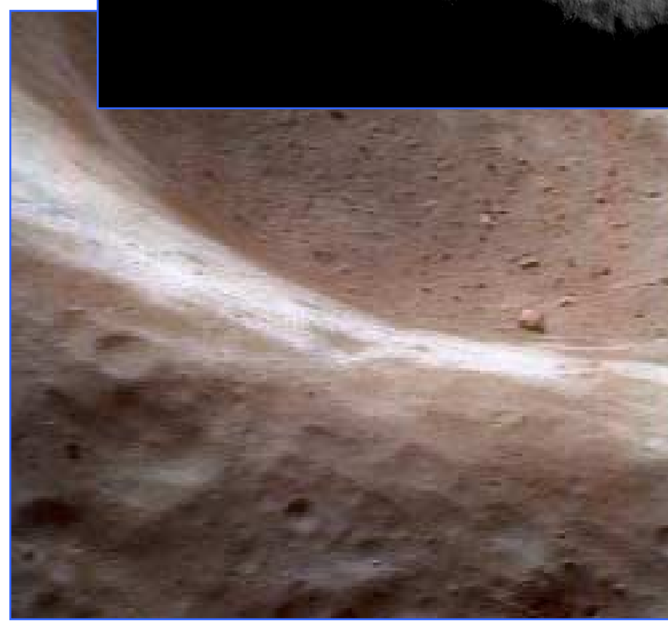
Challenges

- **Human exploration of space is inherently risky**
- **Goal of research is to:**
  - **Identify** risks,
  - **Understand** risks and reduce uncertainties associated with predicting them, and
  - **Manage** risks by preventing them or reducing their effects to acceptable levels





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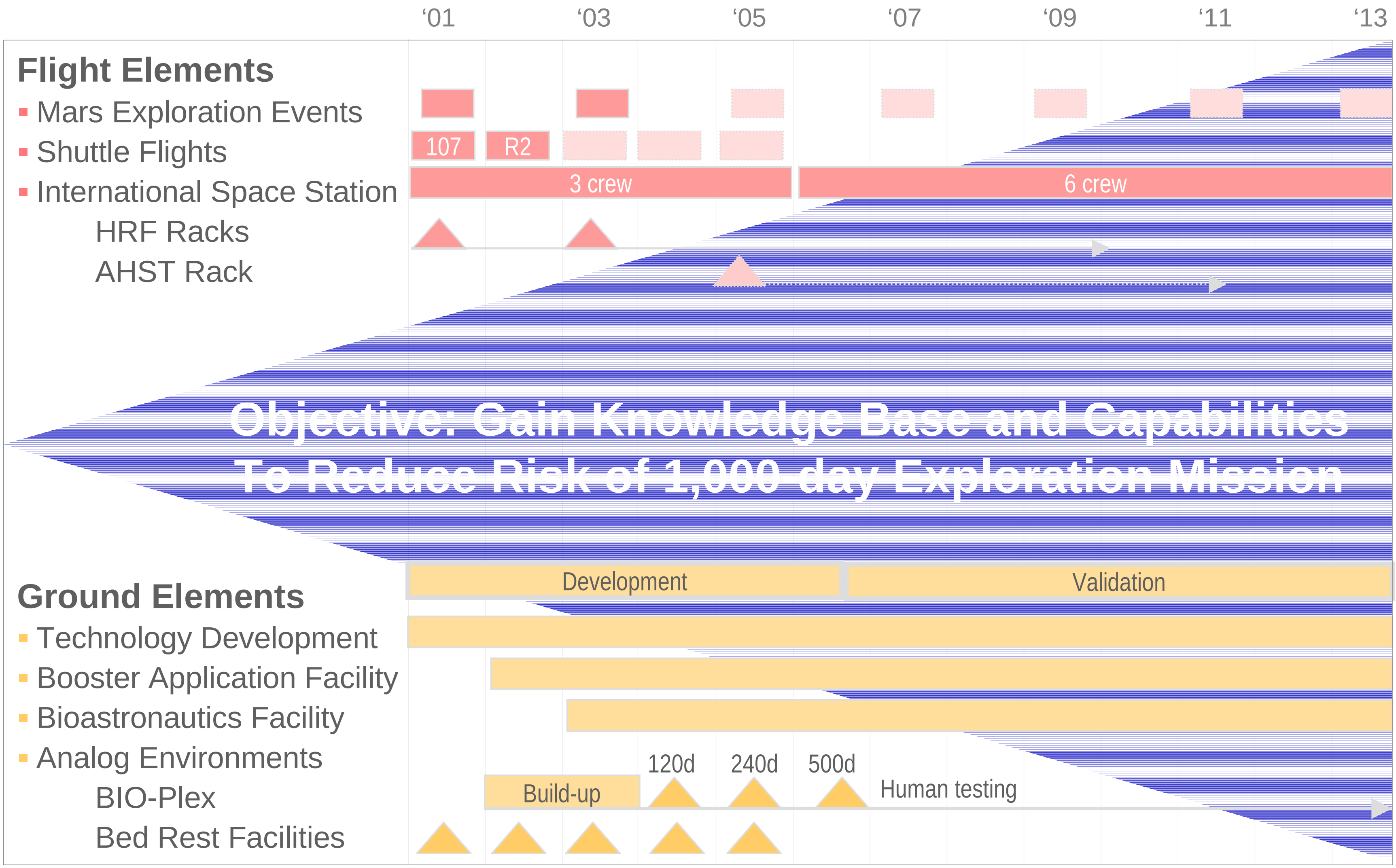
Strategic Roadmap



HRF: Human Research Facility

AHST: Advanced Human Support Technology

Bioastronautics Elements

Space Medicine and Health Care Systems

- Medical care adapted for autonomous function
- Expertise in medical care in hypogravity environments
- Informatics, medical modeling, and simulation—from human to genome—that facilitates diagnosis, therapy, and training

Habitation/ Environmental Health Systems

- Habitation systems capable of supporting humans without Earth resupply for up to 1000 days
- Robust EVA technology for frequent space and surface activity
- Radiation protection technologies or protocols for LEO and deep space environments
- Advanced environmental control system capable of decision making and adjustment

Human Adaptation/ Countermeasures

- Validated countermeasures (mechanical, operational, and pharmaceutical) for up to 1000 days
- Decision on utility and design of artificial gravity countermeasures

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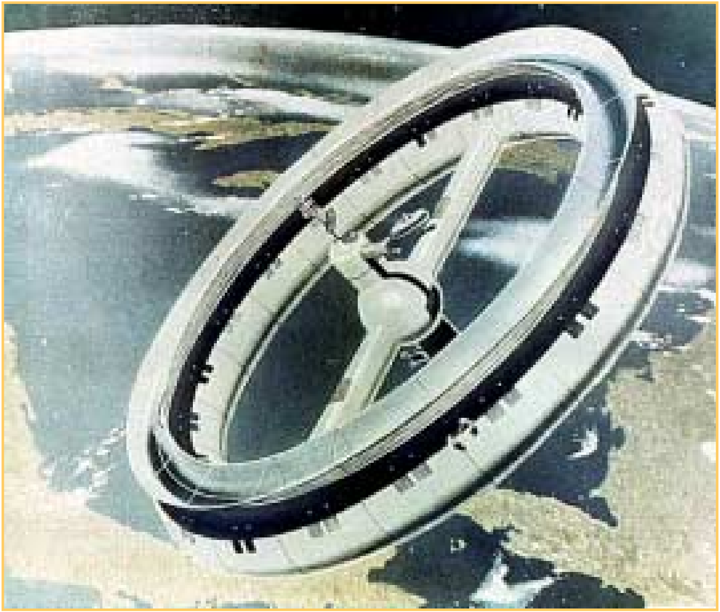
Artificial Gravity

- Workshop held January 1999 to:
  - Debate the merits of artificial gravity (AG) as a countermeasure, and
  - Develop a research and development plan



- Workshop conclusions include:
  - AG may be most effective if combined with existing countermeasures
  - AG research should not preclude other countermeasure research or development
  - Modeling cannot substitute for systematic studies of the human response to AG

Physiological Requirements

To validate AG as an effective countermeasure for the bone, muscle, cardiovascular, neurovestibular, and other target physiological systems*:

How much AG is needed to maintain physiological function/ performance?

- What are the physiological thresholds for effective gravitational force?
- What minimum and/or optimum g-force should be used during transit?
- Would AG be useful on a planetary surface?

What are the acceptable and/or optimal ranges for radius and angular velocity of a rotating space vehicle?

- What are the untoward physiological consequences of rotational AG?
- What are the physiological limits for angular velocity, g-gradient, etc.?

What additional countermeasures would be required to supplement AG?

* requirements for long-arm/continuous may be different from short-arm/intermittent

Critical Risks

	Bone Loss	Cardiovascular Alterations	Human Behavior & Performance	Immunology, Infection & Hematology	Muscle Alterations & Atrophy	Neurovestibular Adaptation	Radiation Effects	Clinical Capability	Other
Type I	Acceleration of Age-Related Osteoporosis (1) - 9 Fractures (Traumatic, Stress, Avulsion) & Impaired Fracture Healing (2) - 10	Occurrence of Serious Cardiac Dysrhythmias (1) - 13	Human Performance Failure Because of Poor Psychosocial Adaptation (1) - 18 Human Performance Failure Because of Sleep and Circadian Rhythm Problems (2) - 19		Loss of Skeletal Muscle Mass, Strength, and/or Endurance (1) - 28	Disorientation and inability to perform landing, egress, or other physical tasks, especially during/after g-level changes	Carcinogenesis Caused by Radiation (1) - 38 Damage to Central Nervous System from Radiation Exposure (2) - 39	Trauma & Acute Medical Problems (1) - 43 Toxic Exposure (2) - 44	Inadequate Nutrition (Malnutrition) 7, 8, 53
Type II		Impaired Cardiovascular Response to Orthostatic Stress (1) - 14			Inability to Adequately Perform Tasks Due to Motor Performance, Muscle Endurance, and Disruptions in Structural and Functional Properties of Soft and Hard Connective Tissues of the Axial Skeleton (1) - 29	(1) - 33 Impaired neuromuscular coordination and/or strength. (2) - 34	Synergistic Effects from Exposure to Radiation, Microgravity and Other Spacecraft Environmental Factors (3) - 40	Altered Pharmacodynamics and Adverse Drug Reactions (3) - 45	Post-Landing Alterations in Various Systems Resulting in Severe Performance Decrements and Injuries 49
					Inability to Sustain Muscle Performance Levels to Meet Demands of Performing Activities of Varying Intensities (2) - 30		Early or Acute Effects from Radiation Exposure (4) - 41		Habitation and Life Support 1,2,3,4,5,6,51,52
	Injury to Soft Connective Tissue or Joint Cartilage, and/or Intervertebral Disc Rupture With or Without Neurological Complications (3) - 11	Diminished Cardiac Function (2) - 15	Human Performance Failure Because of Human System Interface Problems and Ineffective Habitat & Equipment Design, etc. (3) - 20	Immunodeficiency/ Infections (1) - 22	Propensity to Develop Muscle Injury, Connective Tissue Dysfunction, and Bone Fractures Due to Deficiencies in Motor Skill, Muscle Strength and Muscular Fatigue (3) - 31	Impaired cognitive and/or physical performance due to motion sickness symptoms or treatments, especially during/after g-level changes. (3) - 35	Radiation Effects on Fertility, Sterility and Heredity (5) - 42	Illness and Ambulatory Health Problems (4) - 46	
Type III	Renal Stone Formation (4) - 12	Manifestation of Previously Asymptomatic Cardiovascular Disease (3) -16 Impaired Cardiovascular Response to Exercise Stress (4) -17	Human Performance Failure Because of Neurobehavioral Dysfunction) (4) - 21	Carcinogenesis Caused by Immune System Changes (1) - 23 Altered Hemo- & Cardio- dynamics from Altered Blood Components (1) - 24	Impact of Deficits in Skeletal Muscle Structure and Function on Other Systems (NR) - 32	Vestibular contribution to cardioregulatory dysfunction. (4) - 36 Possible chronic impairment of orientation or balance function due to		Development and Treatment of Decompression Illness Complicated by Microgravity-Induced Deconditioning (5) - 47 Difficulty of Rehabilitation Following Landing (6) - 48,54	
				Altered Wound Healing (2) - 25 Altered Host-Microbial Interactions (3) - 26		microgravity or radiation. (5) - 37			
				Allergies and Hypersensitivity Reactions (3) - 27					

What Next?

- Build on previous and ongoing work
  - Fundamental knowledge amassed during past ground and flight biomedical research
  - Apply knowledge base to applications and solutions for safer human operations in space
- Employ new research resources coming online
  - ISS research opportunities
  - Ground analogs
  - Booster Application Facility
- Leverage new and unique capabilities
  - Fulfill NASA's vision for science institutes through the National Space Biomedical Research Institute (NSBRI)
  - Focus on NASA issues with participation from scientific community
  - Cooperate with other Federal Agencies (e.g., NIH)
  - Incorporate revolutionary and evolutionary technologies, such as smart medical systems, biologically-inspired technologies, and nanotechnologies

Outcome: Reducing Risk for Products

- Enhance ability to deliver crew health care
- Understand and manage biomedical risks of human space flight
  - Significant participation by external scientific community
  - Requirements define program priorities and decisions (cost/benefit analyses)
- Promote safe and effective role of humans in NASA's exploration mission through enhanced national and international partnerships
- Increase education and outreach activities

Radiation

Problem Definition

- Risks of cancer, late nervous system effects, and cataracts a safety concern for exploration:
  - Epidemiological data for space radiation does not exist
  - Excessive shielding costs required to attenuate high-energies of space radiation
  - Biological damage to cells/tissue from heavy ions qualitatively different from x-rays and gamma-rays
  - Biological effects of heavy ions not quantified to support risk prediction in humans
  - Effectiveness of shielding approaches can not be understood until biological effectiveness of heavy ions is determined
- Dose limits for exploration not defined because of lack of knowledge, summarized in 1997 NAS Report:

"The fact that the present report reaches conclusions similar to the 1989 report of the NCRP underscores the need for additional resources and facilities in order to understand qualitatively the radiation biology with interplanetary flights"

Solution

- Recommendations by NAS, NCRP, and radiation protection community have remained constant since 1970:
  - Develop heavy ion accelerator to simulate space radiation
  - Determine relative biological effectiveness factors (RBE) for protons and heavy ions using animal cancer models
  - Perform critical research to optimize use of data to predict cancer risks in humans
  - Research needed to understand effects of heavy ions and protons on central nervous system (CNS)
  - Use new radiobiology knowledge and data to develop optimal shielding approaches
  - Develop technologies to provide better advanced warning of solar particle events
  - Measure Mars radiation environment
  - Perform research on development of biological countermeasures
  - Understand role of individual variations in radiation sensitivity

Risks and Dose Limits

Risk

- Deterministic effects include acute radiation sickness, damage to central nervous system (CNS), or cataracts
  - *Acceptable risk*: zero; dose limits ensure threshold not exceeded
- Stochastic effects include cancer, hereditary effects, or neurological disorders; occur with probability proportional to dose
  - *Acceptable risk:* current dose limits ensure less than 3% probability of excess cancer death; ALARA Principle is used to stay well below limits
    - » Limit of 3% excess cancer deaths originates from comparisons to other occupational injuries
    - » Dose-to-risk conversion highly dependent on age and sex
  - Health risks from stochastic effects continue after mission completion

Risk Acceptability

- NASA sponsored NCRP Symposium, "Acceptability of Risk from Radiation -- Application to Human Space Flight" (1996) included Astronaut participation and advocated continued use of ALARA
  - "no magic formula" but "process of negotiation that integrates … social, technical and economic factors," weighing risks and benefits

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Risk Prediction and Uncertainties

- Conventional system of risk projections

  Risk = Risk Coefficient x Dose x Quality Factor

  - Risk coefficient from human epidemiology data and is dependent on tumor type, age at exposure, sex, time after exposure
  - Quality factors are based on values of relative biological effectiveness factors (RBE) for radiation of interests determined in animal or cellular models

    (RBE = Dose of Gamma-rays / Dose of heavy ion causing equal effect)
- Risk uncertainties:
  - Biological Uncertainties
    - Human epidemiology data and transfer from WWII Japanese to US populations
    - Extrapolation of epidemiology data (high dose-rate) to low dose-rates
    - Quality factors (RBE) as a function of ion type and energy
  - Physical Uncertainties:
    - Knowledge of environment
    - Transport of environment in shielding and tissue

Risk Prediction and Uncertainties continued

- Central Nervous System Damage: 1970, 1973, and 1997 NAS Reports noted special concern for damage to non-renewable cell systems, especially CNS, from HZE ions
- Late degenerative damage to neurons and behavioral changes, including accelerated aging are seen in lower species models
  - » Late degradation of DNA and altered dopamine expression observed in animal models exposed to heavy ion beams while not observed with X-rays or neutrons
  - – Late effects (dementia, degraded IQ's, etc.) in patients who have undergone radiation therapy for primary and secondary brain tumors have become more prominent in recent years as survival years of patients have improved (> 2 years)
  - – Insufficient information currently available to estimate CNS risks to astronauts for Mars mission
    - » Possible detriment from this risk not included in career dose limits

Exploration Cancer Risk Assessment

(Solar Minimum with 4 g/cm^2 Al shield and High Density Mars Atmosphere)

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Lifetime Cancer risks for 40 year old Females

%Probability of Excess Cancer Death and 95% C.I.

Mission	days	0 cm H_2O shield	10 cm H_2O shield
L2	62	0.60 [0, 3.3]	0.45 [0, 2.7]
Lunar	20	0.13 [0, 0.7]	0.09 [0, 0.6]
Mars-1	360	3.3 [0, 18.0]	2.5 [0, 14.6]
Mars-2	660	6.2 [0, 34.0]	4.6 [0, 27.5]
Mars-3	1000	5.7 [0, 30.8]	4.5 [0, 25.5]

Lifetime Cancer risks for 40 year old Males

%Probability of Excess Cancer Death and 95% C.I.

Mission	days	0 cm H_2O shield	10 cm H_2O shield
L2	62	0.40 [0, 2.0]	0.27 [0, 1.6]
Lunar	20	0.08 [0, 0.41]	0.06 [0, .34]
Mars-1	360	2.0 [0, 10.8]	1.5 [0, 8.8]
Mars-2	660	3.7 [0, 20.4]	2.8 [0, 16.5]
Mars-3	1000	3.4 [0, 18.5]	2.7 [0, 15.3]

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Recommendations

- Reduce uncertainty:
  - Realistic evaluations indicate uncertainties in risk projections for exploration missions are a factor of 4-5; lower than cited in NAS (1997)
  - Risk uncertainties dominated by limited knowledge of radiation quality as a function of radiation type and dose-rate effects
  - Expansive radiobiology research needed to narrow these factors, major uncertainty factor is data and understanding of late effects from heavy ions
  - Further improvements in knowledge in radiation environment and transport properties needed, especially neutron effects
    - Special studies needed on CNS risks; no approach to estimate possible late risks exits
- Approaches for mitigation:
  - A combined approach in several areas can lead to significant risk reduction
    - Use of light mass materials in spacecraft design (~25%)
    - Operational (~25%)
    - Use of pharmaceuticals (including anti-oxidants) (> 25%)

Summary

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- The construction of Booster Application Facility (BAF) will allow NASA to collect critical data and perform research to reduce the uncertainties in risk projection and to develop effective mitigation approaches
- BAF Utilization plan is needed to support exploration mission design:
  - Long-term timelines for data collection using animal models places priority on optimizing use of BAF upon completion in FY02
- Focus:
  - Data collection to determine dose response and RBE's or other relative risk factors for solid tumors and leukemias from heavy ions
  - Seek partnerships in radiobiology research:
    - » NSBRI, DOE and NCI on cancer research
    - » NIH's National Institute of Aging (NIA) on CNS effects
  - Program objectives:
    - » Expand support for shielding and material technologies
    - » Perform Mars environment measurements
    - » Improve technology for early SPE warning

Backup Charts

Bioastronautics Overview

Research and Development

Integrated To Capitalize on Existing Center Strengths

JSC
- Crew rehabilitation and training
- Baseline data collection
- Biomedical and clinical research
- Advanced systems in medicine, life support, and safety
- Biotechnology and bioengineering

JPL
- Nanotechnology
- Human-machine interfaces

ARC
- Cyber-medicine
- Medical informatics
- Human-machine interfaces

MSFC/GRC
- Materials
- Combustion
- Fluids
- Commercial

Budget

Bioastronautics Budget

- NASA Bioastronautics Initiative submitted as part of the Agency FY01 Presidential Budget
  - Less than 30% of original request was authorized in final Agency submit
  - Results in a reduced objective plan and extends the targets from 2010 to 2015
- FY2002 Agency submit to OMB includes OLMSA Bioastronautics Initiative to assure funding for focus on ISS long duration crew stay risk reduction
  - Present baseline does not accommodate timely risk reduction for ISS long duration
  - Does not focus on objectives beyond ISS

Bioastronautics Budget continued

- Bioastronautics submit via the Decadal Planning Team (DPT) is for breakthrough technologies and research beyond present funding/focus areas
  - Builds on existing research
  - Gains synergistic effect from present program
  - Success dependent upon above-mentioned Bioastronautics content and augmentation for ISS focus
    - Reductions to 'core' program will diminish and undermine objectives targeted in the DPT submit
- Additional resources beyond the DPT augmentation are required to meet the original scope of the Bioastronautics Initiative's objectives and to provide the associated knowledge and technology for the DPT targets

Decadal Planning Team Submit

- Identified three major areas for accelerated Bioastronautics research related to DPT
  - Radiation protection beyond low Earth orbit – research and technology
  - Development of advanced technologies for autonomous human operations
  - Definition and validation of artificial gravity concept
- General philosophy:
  - Pursue tasks that have higher risk/potential breakthrough in previously defined areas of research
  - Overall objective: invest in critical key risk mitigation areas to enable success within scope of DPT thrust on accelerated schedule in coordination with the baseline Bioastronautics investments
- DPT funds would be applied to current and upcoming solicitations inclusive of directed research investments to ensure viable technology development and application

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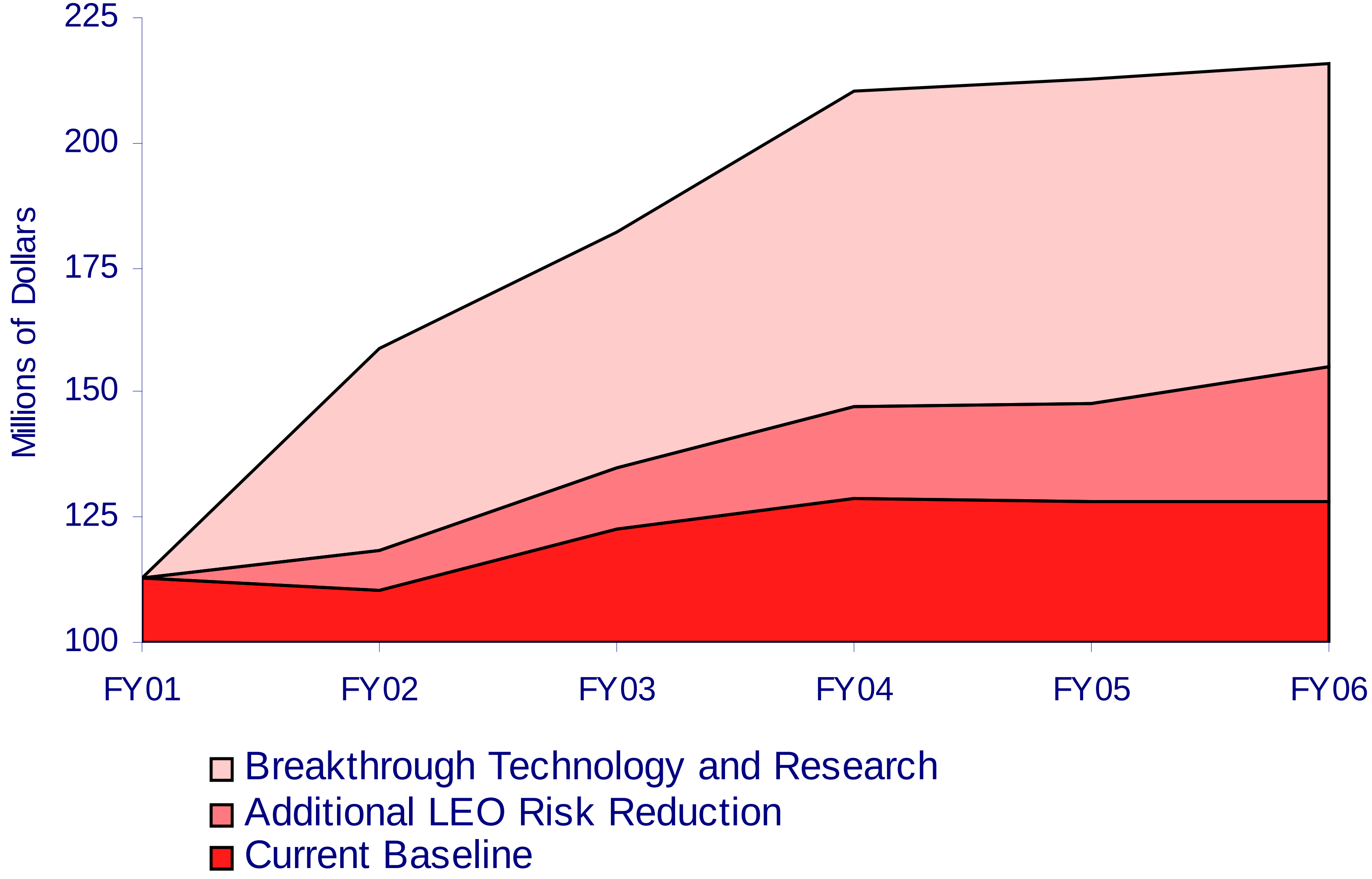
Bioastronautics Budget Potential

Title	FY01	FY02	FY03	FY04	FY05	FY06	Total FY02-FY06
FY2001 PBS Baseline - OLMSA	112.86	110.59	122.69	128.90	128.10	128.10	618.38
(Includes the initial increase for Bioastronautics and adjustments in POP00)							
FY2002 Budget Augmentation Submit for Bioastronautics by OLMSA		8.00	12.00	18.00	20.00	27.00	85.00
(Increase to focus on Low Earth Orbit Risk Reduction)							
FY2002 Budget Augmentation for Bioastronautics within DPT Request		40.45	47.70	63.20	64.70	60.90	276.95
(Focus on Break through technologies and research)							
Totals with Augmentation in FY01 and potential FY02 PBS $'s M	112.86	159.04	182.39	210.10	212.80	216.00	980.33

Bioastronautics Budget Potential



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Decadal Planning Team Submit

Title	FY02	FY03	FY04	FY05	FY06	Total
Radiation Protection Beyond Low Earth Orbit	**8.80**	**8.80**	**11.25**	**13.50**	**14.50**	**56.85**
Risk Assessment Models	4.00	4.00	6.00	7.00	6.00	27.00
Pharmaceutical C/M	2.00	2.00	2.00	2.00	4.00	12.00
Radiation Shielding/Materials	1.50	1.50	1.50	1.50	2.00	8.00
Radiation Accelerator Utilization	1.30	1.30	1.75	3.00	2.50	9.85
Autonomous Human Operations/ Survival in Isolated Environments	**23.30**	**29.00**	**38.30**	**37.60**	**35.90**	**164.10**
Advanced EVA Technologies	9.00	8.00	7.00	3.50	3.50	31.00
Smart Monitoring & Control Systems for Closed Life Support	5.00	8.00	15.00	12.00	12.00	52.00
Optimized Closed Loop Life Support	6.00	8.00	10.00	15.00	15.00	54.00
Advanced Food Technologies **- NEW**	0.80	1.75	2.10	2.60	1.90	9.15
Smart Medical Systems	2.50	3.25	4.20	4.50	3.50	17.95
Artificial Gravity	**8.35**	**9.90**	**13.65**	**13.60**	**10.50**	**56.00**
Concept/Design Trade Studies	0.30	0.45	0.60	0.10	0.10	1.55
Ground Simulation Studies	1.50	2.25	2.75	3.00	2.50	12.00
In-flight Design Concepts	3.28	3.60	5.15	5.25	3.95	21.23
Short-arm Centrifuge	1.58	1.60	2.30	2.50	1.65	9.63
Long-arm Centrifuge/Tethers	1.70	2.00	2.85	2.75	2.30	11.60
Totals	**40.45**	**47.70**	**63.20**	**64.70**	**60.90**	**276.95**

Challenges of Human Spaceflight

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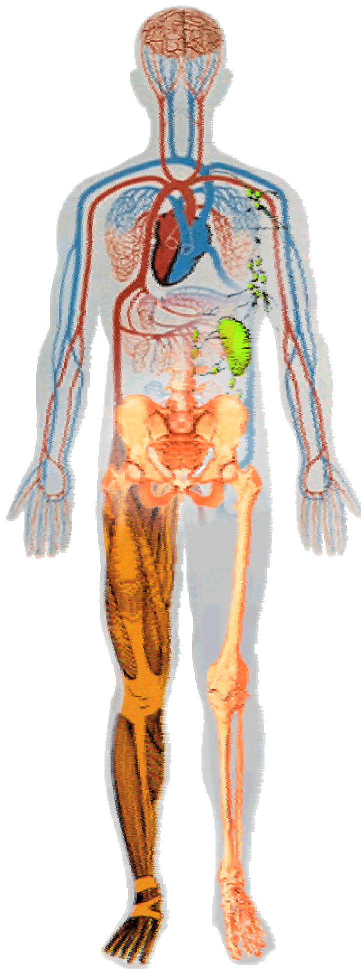
Challenges

Physiologic challenges require the development of specific countermeasures to minimize harmful effects

- Balance disorders
- Cardiovascular deconditioning
- Decreased immune function
- Loss of muscle and bone mass



Operational challenges require strategic research and development to maximize crew performance

- Psychosocial health
- Human factors
- Food and nutrition
- Advanced life support systems
- Radiation exposure

Radiation

Space Radiation Health Program Rationale

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- **What Is Radiation Risk (Effect and Uncertainty) to Humans in Space?**
  more cost effective to do science at ground-based laboratories

Bomb Survivors

LET-dependent quality factor

organ dose

immune system and other effects of weightlessness

Epidemiology

- **What Is Radiation Risk to Humans on Earth?**
  cannot irradiate humans

Life shortening Late effects

Carcino-genesis

Dose rate effects

In vivo studies of organisms

- **What Is Radiation Risk for Small Mammals?**
  need to define mammals: mice? rats? (statistics, data base)

Harderian gland

nude mice transgenic mice,rats

In vitro studies of cells, tissues

- **What Are Radiation Effects on Living Cells?**
  need to study at molecular and cellular level

Models

Molecular biology, biophysics

- **What Are the Mechanisms of Radiation Action?**
  transformation, mutation, genomic instability, oncogene activation, suppressor deletion, apoptosis, carcinogenesis

Integrated Space Radiation Protection Plan

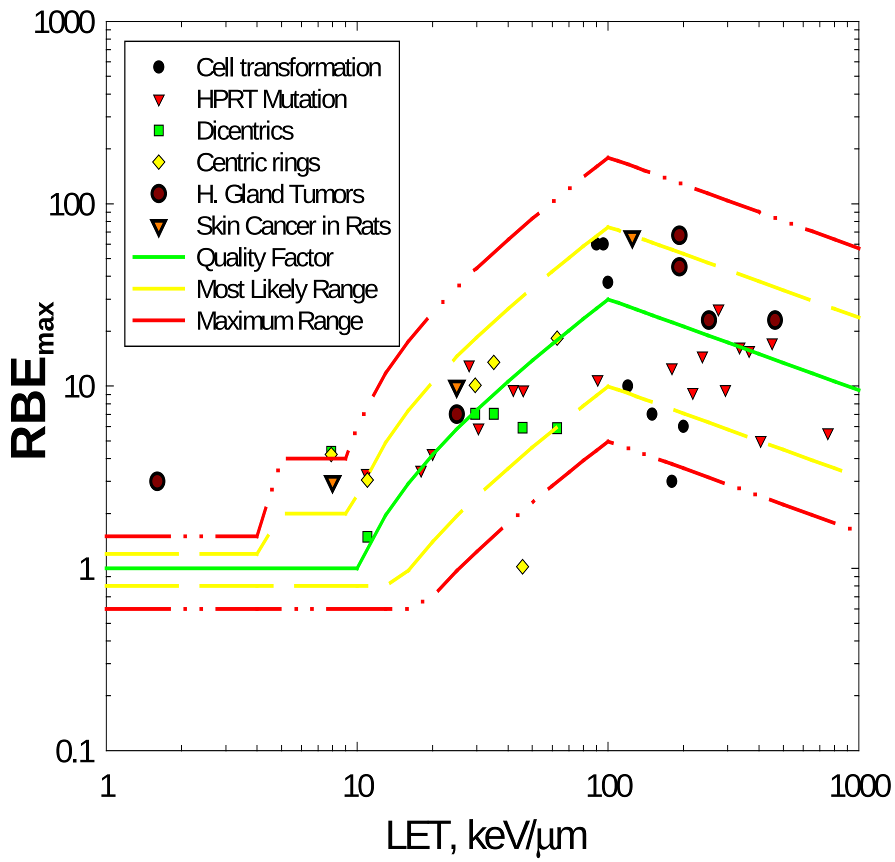
- Integrated Space Radiation Office in Bioastronautics Institute to lead achievement of radiation safety goals:
  - Critical path for reduction in risk projection uncertainties and development of biological countermeasures based on NAS/NCRP findings
  - Ground-based research facilities development and usage (Code U)
  - Mission support, Astronaut Health (Code M and U)
  - Integrate knowledge on space environments (Code S and M/NOAA National Oceanic and Atmospheric Administration)
  - Establish Radiation Shielding and Materials Technologies Task (Code U and M)
  - Integration of new radiobiology results for risk assessment (Code U)
  - Integration of biological countermeasures (Code U and M)
- Collaborative with other US Institutions (academia, NSBRI, National Labs), Federal Agencies (DOE, NCI, DOD) and international partners
- Bioastronautics Initiative will provide resources for vital research

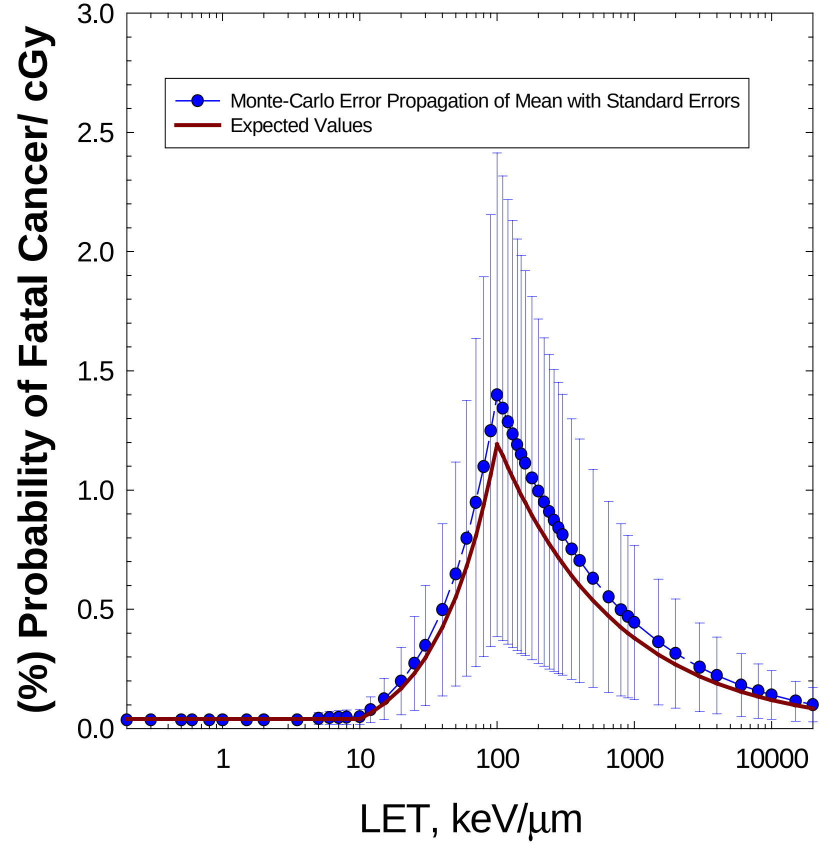
UTICS

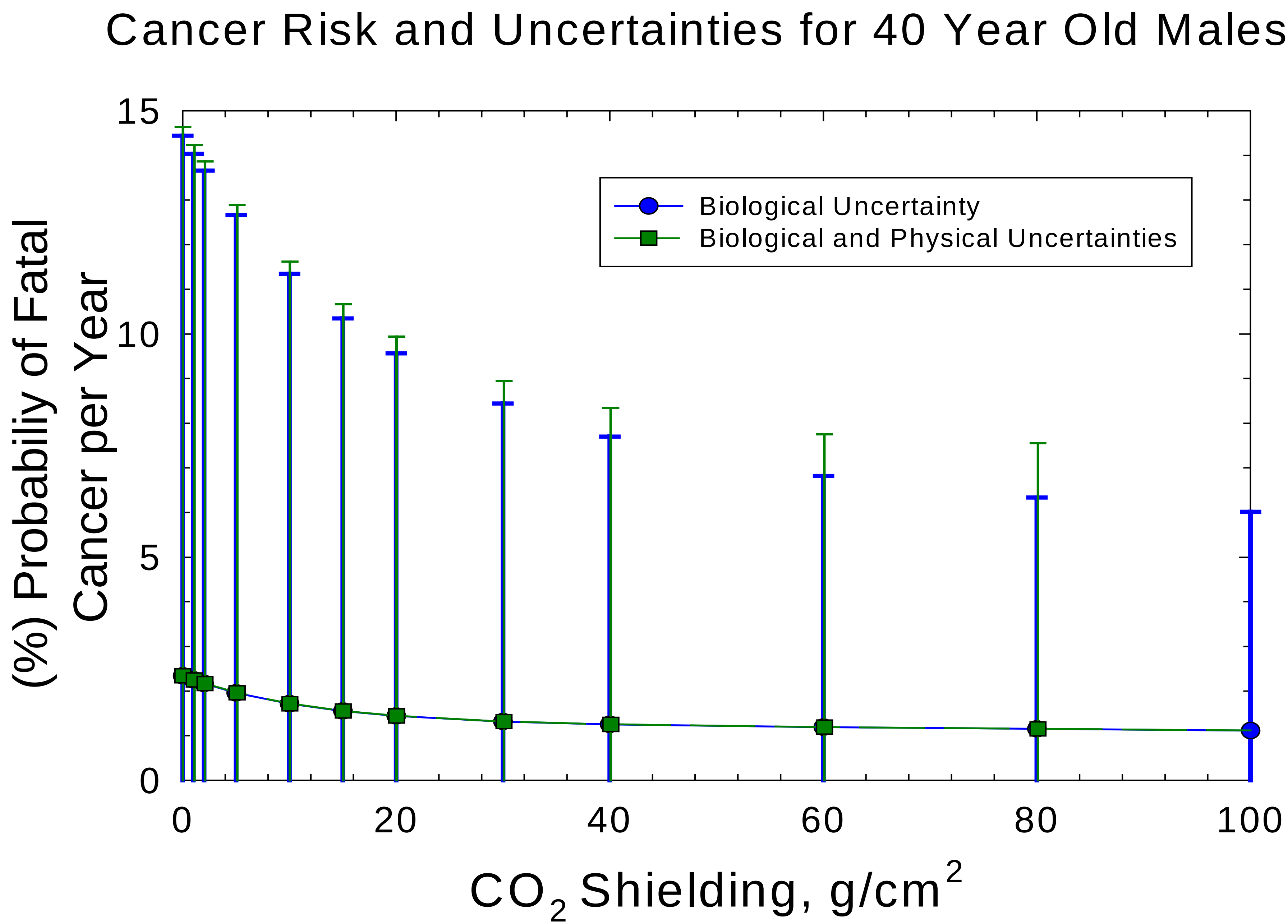
Wye River Retreat

Cancer Risk Estimates

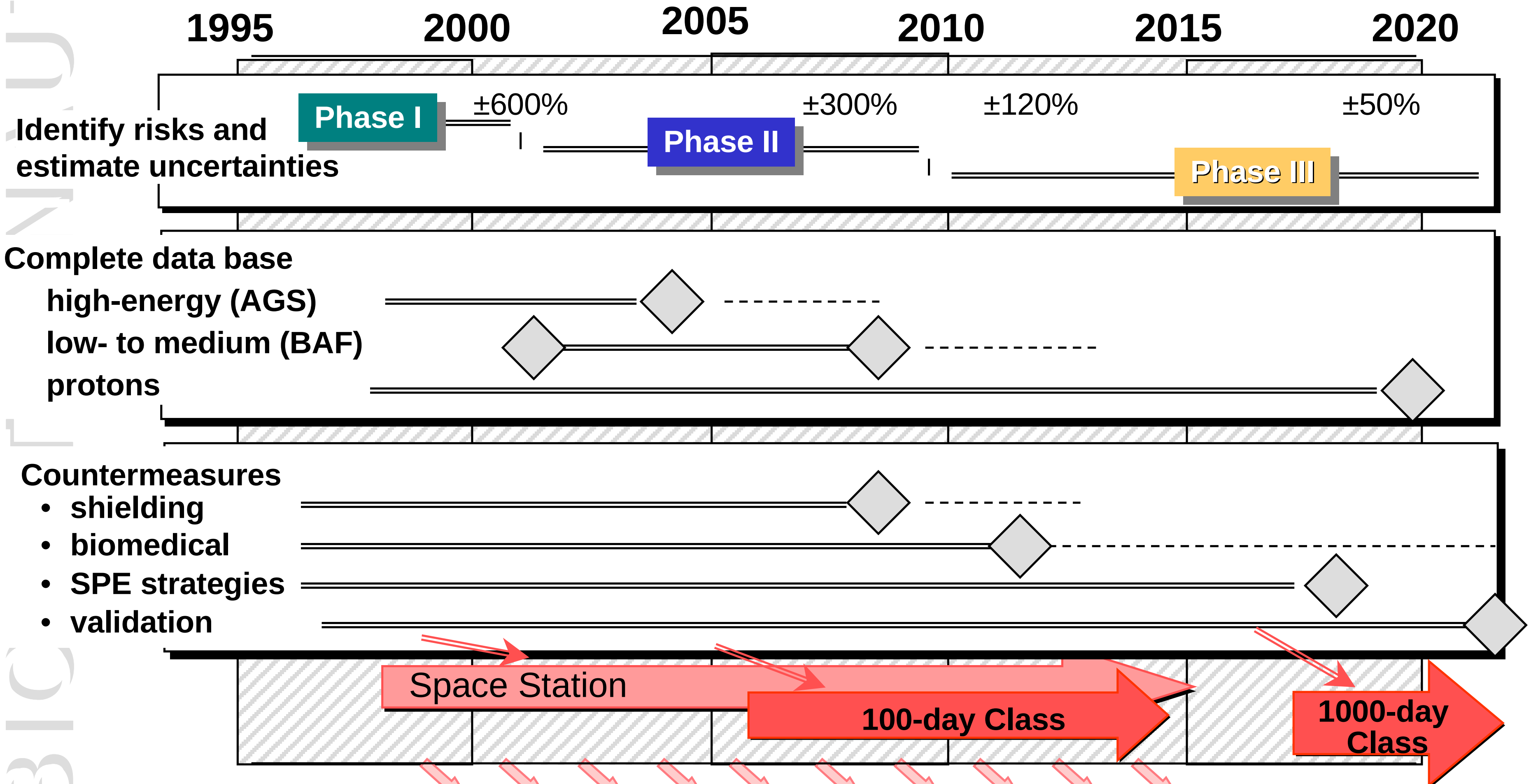
- NCR and NCRP approach of uncertainty propagation of risk factors
  - Include epidemiology, dose-rate, quality factor, and physical uncertainties
- 95% Confidence intervals(C.I.) for exploration scenarios using transport and spacecraft/organ shielding models






Cancer Risk and Uncertainties for 40 Year Old Males
(%) Probabiliy of Fatal Cancer per Year
CO2 Shielding, g/cm2
Biological Uncertainty
Biological and Physical Uncertainties
0
5
10
15
0
20
40
60
80
100

Space Radiation Research: Phased For Exploration



Applications: **cancer, aging, crops, electronics, communications**

Critical Path Roadmap

Critical Path Roadmap (CPR) Process

- **What?**
  - Focused on most demanding scenario: long duration, highly autonomous interplanetary missions
- **How?**
  - Stage 1: Risk Identification and Characterization
  - Stage 2: Further Risk Identification, Characterization, and Ranking
  - Stage 3: Cross-Risk Prioritization

Why?

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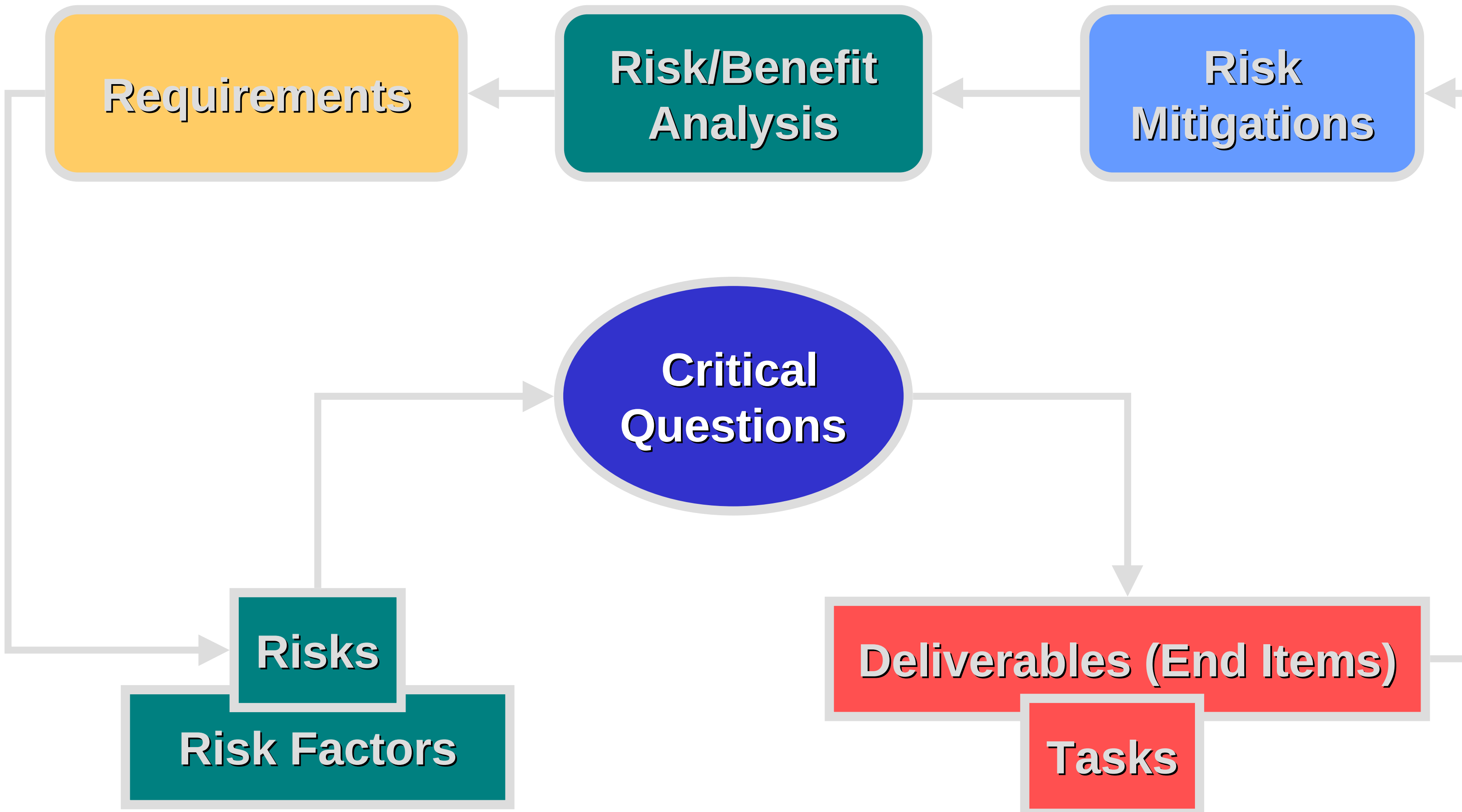
Purpose

- Provide foundation ensuring crewed spaceflight is as safe, productive and healthy as possible
- CPR is a tool used to help track which risks are to be mitigated, and the completeness of that mitigation

Goals

- Address 55 CPR Type I, II, and III risks lacking validated countermeasures
- Reduce to manageable Type IV acceptable risks
- Timeline for countermeasures identification and validation: resolve critical path risks within the decade

Key Elements



Summary of Risk Types

	Demonstrated Serious Problem	Suspected Serious Problem	Demonstrated Problem	Suspected Problem
No Countermeasure Concept	I	II	II or III	III
Countermeasure Concept but No Ground Validation	II	II	II or III	III
Countermeasure Concept but No Space Flight Verification	III	III	III	III
Effective Operational Countermeasure	IV	Not Applicable	IV	Not Applicable

Risk Assessment and Quantification

Strategic Risk Management

Plan Objectives

- Construct comprehensive Bioastronautics medical, mission, and program risk profiles
- Compare human flight-based risks with appropriate Earth-based risks
- Facilitate the effective communication of risks to other organizations within NASA
- Facilitate institution of measurable cost-effective mitigations or countermeasures
- Provide cohesive, reliable, and valid risk management efforts to Bioastronautics
- Anticipate and prevent major disruption to any missions

Strategic Risk Management

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- Project Planning
  - Establish scope, deliverables, and timeline
- Evaluation Planning
  - Develop master matrices and data collection tools
- Risk Identification
  - Identify processes in place to control risk and sources of information
  - Conduct meetings with subject matter experts and operations
- Risk Quantification
  - Quantify risk probability and severity of impact
  - Categorize risks and compare to Earth-based risks
  - Develop total risk profile
- Risk Evaluation
  - Evaluate short- or long-duration countermeasures for mitigation
- Risk Resolution
  - Evaluate alternatives for risk mitigation (cost vs. benefits)
- Final Project Report

Stages of Strategic Risk Management

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Clinical Care

Challenges of Space Medicine

- Limited resources
  - Mass
  - Volume
  - Power
  - Bandwidth
- Medical training and expertise
  - Limitations on crew time
- Distance
- Space environment
  - Radiation
  - Vacuum
  - Isolation and confinement
  - Micro- or partial gravity
  - Recycled air and water

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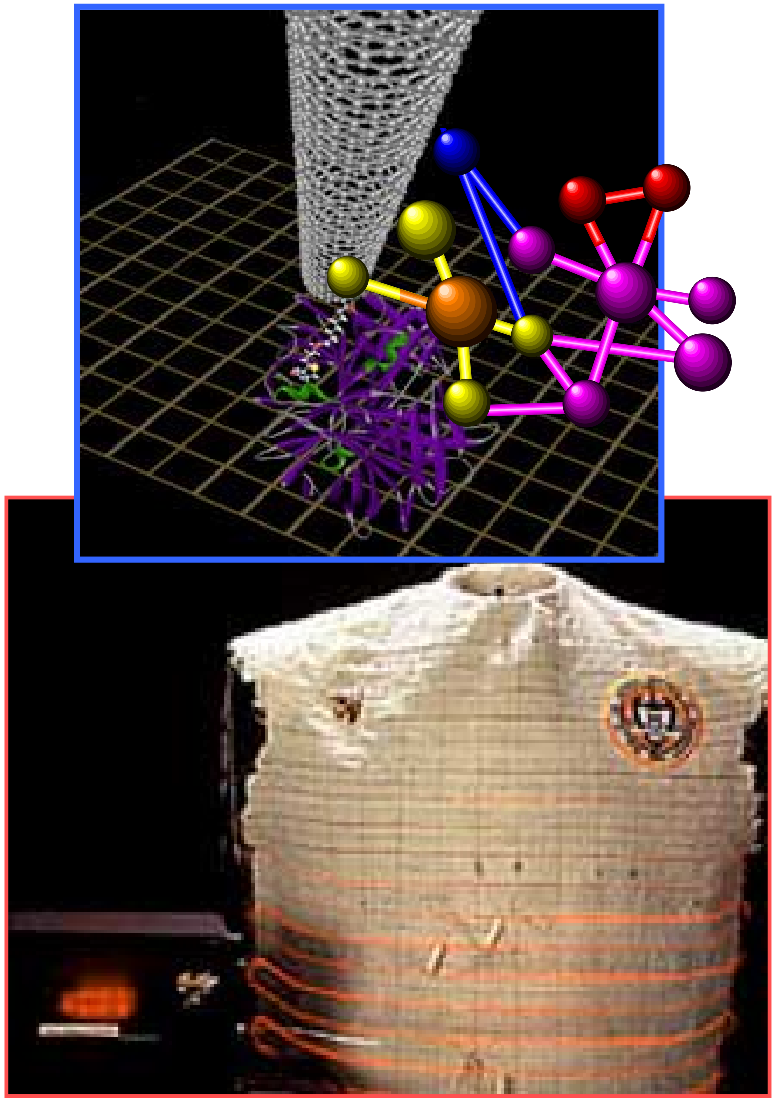
Clinical Problems

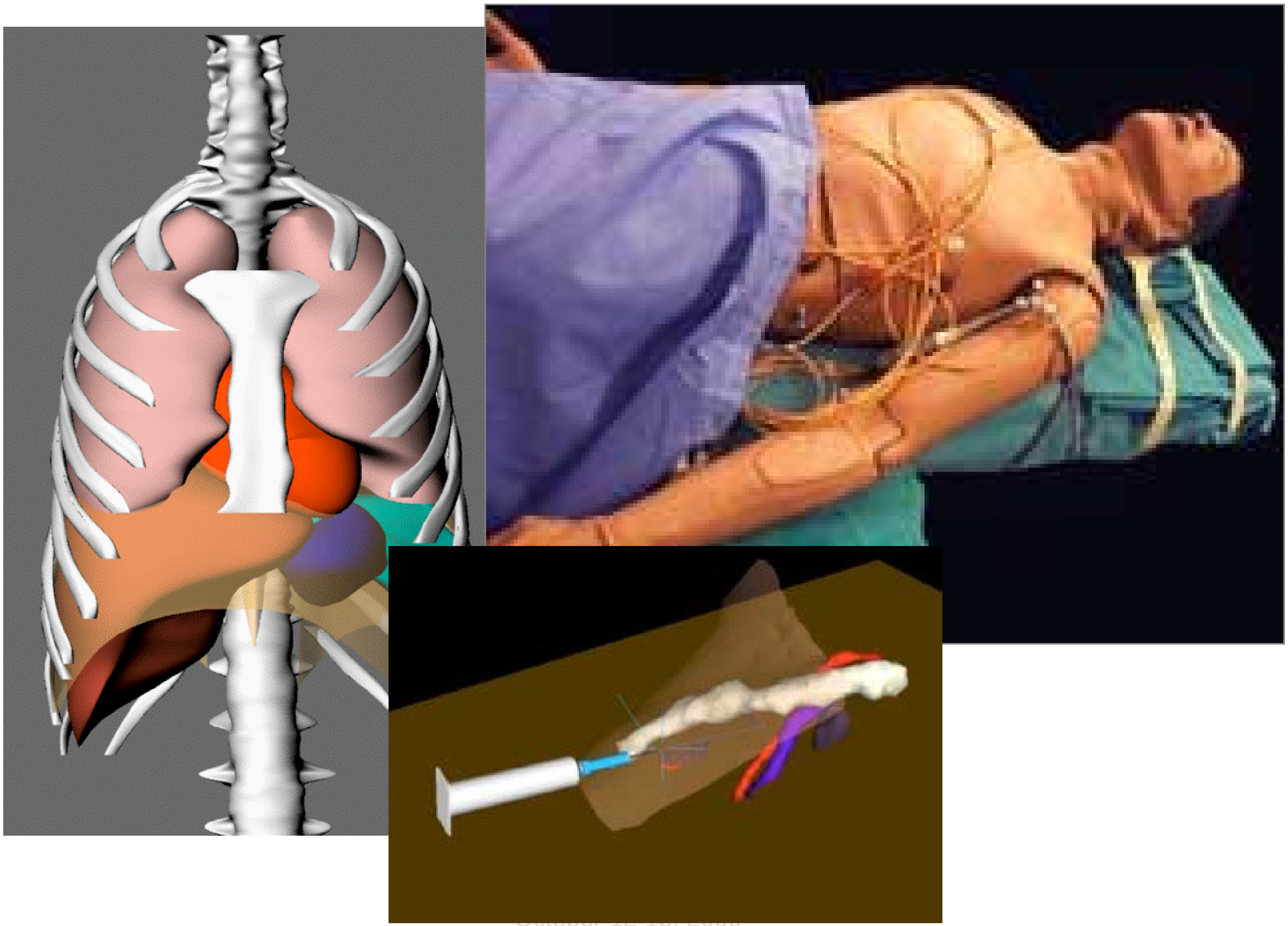
- Expected illnesses and problems
  - Orthopedic and musculoskeletal problems
  - Infectious, hematological, and immune-related diseases
  - Dermatological, ophthalmologic, and ENT problems
- Acute medical emergencies
  - Wounds, lacerations, and burns
  - Toxic exposure and acute anaphylaxis
  - Acute radiation illness
  - Dental, ophthalmologic, and psychiatric
- Chronic diseases
  - Radiation-induced problems
  - Responses to dust exposure
  - Presentation or acute manifestation of nascent illness

Trends in Medical Care

- Portability and application of nanotechnology
- Minimally invasive diagnostic systems capable of detecting abnormal human function across all body systems
- Health care approaches appropriate for therapeutic intervention in a wide range of pathological and trauma scenarios



Modeling and Simulation



Informatics

Medical Informatics

- Prioritized by NASA
  - New office established within Bioastronautics: Medical Informatics and Health Care Systems
- Time for crew training:most expensive and limited resource during mission
  - Need for on-board (on-site) system intelligence
  - Change from typical telemetry applications because system must process information at remote site

Technology Needs

Technology: Adaptation and Countermeasures

- Countermeasures are developed to maintain health and performance during flight and upon return to Earth
- Adaptations to spaceflight
  - Fluid shift initiates cardiovascular changes
  - Continual bone demineralization
  - Muscular atrophy
  - Negative calcium balance (concomitant risk for kidney stones)
  - Initial neurosensory and neuromotor dysfunction during transition between different g environments (e.g., space motion sickness of limited duration)
  - Psychosocial adaptation to isolation and confinement
- Further technology development needed for countermeasures involving
  - Exercise regimens
  - Pharmacologic supplements and/or enhanced nutrition
  - Neurosensory and neuromotor monitoring and stimulation
  - Exploration of artificial gravity as a multi-system countermeasure

Technology: Health Care Systems and Clinical Care

- Broader range of health care capabilities needed as medical evacuation to Earth becomes more impractical
- Modeling and simulation technologies
  - Training
  - System integration/testing
- Inflight systems to perform in-vivo, non-invasive analysis and to process/downlink data:
  - Biosensors to monitor blood chemistry, pulmonary gases, and metabolites
  - Real time urine chemistry sensors for automated analysis
  - Small, portable, medical diagnostic equipment, including x-ray and ultrasound imaging systems
  - Trauma and medical care systems (such as resuscitation /stabilization, IV formulation, artificial blood or room temperature blood component storage, portable/ inflatable hyperbaric chamber, portable/wireless physiological monitoring)
  - Pharmaceuticals with extended shelf life
  - Telemedicine systems for orbital operations

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Technology: Advanced Human Support

Life support and environmental monitoring

- Highly reliable, self-sufficient life support systems (recycling air, water and solid wastes) that minimize mass, power, volume and crew time requirements
- Real time, autonomous monitoring of air, water and food for microbial and chemical contamination

Crew accommodations

- Exploration missions require self-sufficient and highly reliable systems and resources
- Technology needs include:
  - Repair and maintenance systems without Earth support
  - Extension of shelf life for diet needs (3 – 5 years)
  - Decision-support systems for critical event response

Technology: Crew Performance

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Human Factors

- Non-intrusive methods for monitoring individual/group performance over time
- Autonomous means for information capture and collection
- Improved user interfaces and displays

Training

- Advanced computer and simulation systems (virtual reality/augmented reality) for refresher training and skill monitoring
- On board training systems for new or infrequent tasks (just-in-time training)

Psychosocial Health

- Continuous, integrated assessment of mental status
- Means for personal communications and recreation through interactive systems
- Adaptive diagnostic system

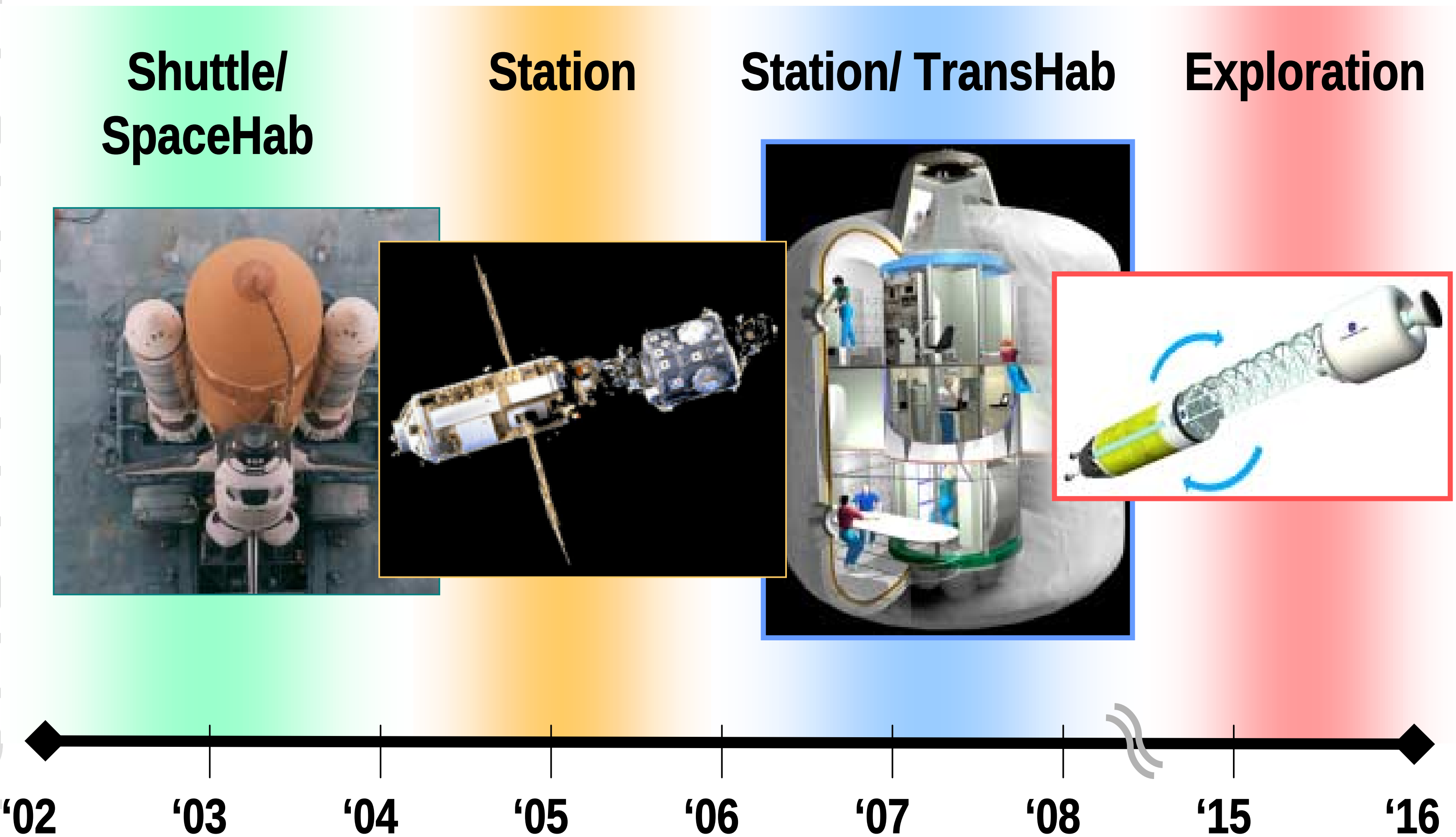
Technology: Radiation Risk and Mitigation

- **Technology development required to reduce/compensate radiation effects**
  - Monitoring the radiation environment and dose received
  - Predicting changes in the radiation environment
  - Developing radiation shielding and pharmacology

- **Specific technologies include:**
  - Active, solid state, personal radiation dosimeter
  - Neutron dosimeter
  - SPE early warning system
  - Improved models for the radiation environment, shielding, and radiation transport
  - Chemical and biological modifiers and radioprotectants
  - Improved composite materials for radiation and hypervelocity impact shielding

Artificial Gravity

Possible Flight Test Progression



Immediate Objectives

- Support and guide existing in-flight centrifuge projects.
- Incorporate specifications into design of long-arm orbital testbed for use on ISS:
  - Largest possible diameter to yield minimal rotation rate
  - Adjustable velocity that yields between 0 and 3 g
  - Space for two or more crewmembers to maneuver easily
- Identify potential opportunities for deploying short-arm human centrifuge aboard the Space Shuttle.
- Implement a peer-review process and/or guidelines for “parametric” research and development activities.

Near-Term Objectives

- Begin funding of ground-based research activities
- Establish joint NASA/NIH research initiative to investigate use of centrifuge devices in treating clinical populations (e.g., osteoporotic patients). Solicit research proposals against these objectives.
- Evaluate which critical questions can be addressed using ISS animal centrifuge.
- Modify and/or expand planned program to include specific objectives and then solicit research proposals.
- Begin AG studies on Space Shuttle using human-powered centrifuge.
- Provide recommendations/requirements to Mars vehicle designers.

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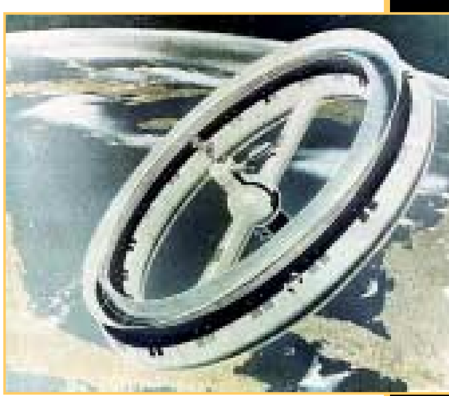
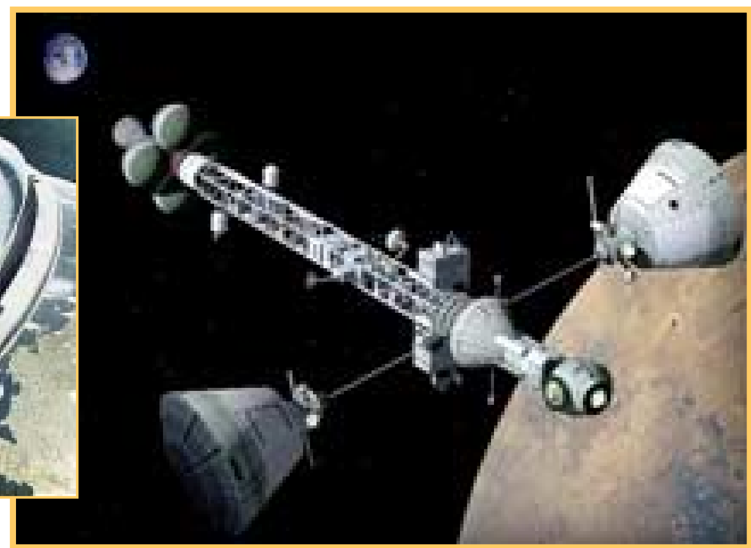
Far-Term Objectives

- Solicit, develop, and perform centrifuge studies with animal and human subjects, both on the ground and in flight.
- Discontinue Shuttle short-arm centrifuge experiments as ISS venues become available.
- Focus funding on AG countermeasure development activities, as warranted by research findings.





NSBRI

National Space Biomedical Research Institute

Mission

Combine the basic research capabilities of the nation's leading biomedical research laboratories with the operational and applied research of NASA to understand and remove the impediments to safe and effective human exploration and development of space

Consortium Institutions

- Baylor College of Medicine (NSBRI Headquarters)
- Harvard Medical School
- The Johns Hopkins University School of Medicine
- Massachusetts Institute of Technology
- Morehouse School of Medicine
- Rice University
- Texas A&M University
- Brookhaven National Laboratory
- Mount Sinai School of Medicine
- University of Arkansas for Medical Sciences
- University of Pennsylvania Health System
- University of Washington

NSBRI Objectives

- Design, implement, and validate effective countermeasures
- Define molecular, cellular, and organ-level responses to foster development of countermeasures
- Establish biomedical support technologies
- Transfer and disseminate biomedical advances in knowledge and technology
- Ensure open involvement by the scientific community, industry, and the public

Behavioral Health and Performance

Primary Factors of Human Performance

Low fatigue
Alert
[Sleep/circadian assessment]

Healthy brain and mood
Focused concentration
[Behavioral medicine]

To Think + To Act = **To Perform**

Adapted to workplace
Motivated
[Operational psychology]

Physical interface to workplace
Sensible workload
[Human-to-system interface]

Risk Mitigation Matrix

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- Risk Mitigation requires **predicting**, **preventing**, **monitoring** and **responding** to these risk areas.

Current Overview of Status:

	Predict	Prevent	Monitor	Respond
Behavioral Health	Poor	Fair	**Cognition-G** Mood-Poor	Fair
Adaptation	Fair	Fair	Poor	***Good***
Human Systems	Poor	Poor	Workload-F Habitability-P	Poor
Sleep and Circadian	Poor	Fair	Poor	***Good***

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Background and Issues

Preventing human performance failure requires countermeasures in four areas :

- Psychological Adaptation: maintain **motivation** through optimized relationships, as well as monitoring and countermeasures
- Human-System Interface: deliver **mission goals "on-time"** through optimized habitat, work planning, information/retraining systems
- Sleep and Circadian: assure **alert, rested crewmembers** through optimized fatigue monitoring and countermeasures
- Behavioral Illness: prevent **'brain drain'** in crewmembers due to behavioral/cognitive injury through monitoring and countermeasures

Advanced Human Support Technology and Advanced Life Support

Advanced Life Support (ALS) Systems

- Required for future human space exploration missions
- Self-sufficiency for air, water and food
- Will dramatically reduce amount of resupply required for these consumables
- Research areas:
  - Atmosphere revitalization: CO_2 removal and reduction, O_2 generation, trace contaminant control
  - Water recovery and management, wastewater processing
  - Waste management: fecal and urine collection and pretreatment, waste processing
  - Food production: crop production, processing, and storage

Advanced Environmental Monitoring and Control (AEMC)

- Reliably monitor gas, liquid, and microbial constituents of a closed loop life support system
- Autonomously analyze and control these constituents to maintain human and system health safely
- Research areas
  - Air monitoring (chemicals): Sampling biologically via inspired sensor technologies, miniaturization
  - Water monitoring (chemicals): Sampling via biologically inspired sensor technologies, miniaturization
  - Microbial monitoring: Sampling via biologically inspired sensor technologies, miniaturization

Advanced Food Technology

- Focuses on research and development work that will enable the provision of a nutritious and safe food system for an exploration-class mission
- Research areas:
  - Food processing
    - Equipment and procedures for processing of BIO-Plex crops into ingredients for food preparation
  - Food packaging
    - Advanced food packaging to extend shelf-life and reduce weight, volume and waste for an exploration-class food system
  - Food preservation
    - Research into methods for extending shelf-life of food products to meet the estimated 5-year shelf-life requirements for an exploration-class mission

Human Factors

Space Human Factors Engineering

Focuses on:

- Role of humans in complex systems
- Design of equipment and facilities for human use, and
- Development of environments conducive to comfort and safety

Research areas:

- Ergonomics and anthropometrics
  - Habitability, safety, tools and equipment
- Human interaction with information and automation systems
  - Interfaces, displays and controls, human/machine function allocation
- Training for frequent tasks
- Workload and performance
  - Workload monitoring and assessment, schedule planning and optimization

Space Human Factors: Critical Risks

- Incomplete planning, design and execution based on inaccurate or inadequate human performance modeling and analysis
- Poor information quality or information management problems for human operations
- Ineffective design of human-system interactions
- Habitability and working conditions inadequate to maintain human performance
- Training system inadequacies

Wye River Retreat

Roadmap for Space Human Factors